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*Total number of authors:*  
16

*Published in:*  
Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2015

*Publication date:*  
2015

[Link back to DTU Orbit](#)

### *Citation (APA):*

Wickert, J., Andersen, O. B., G., B., Cardellach, E., B., C., Gommenginger, C., Høeg, P., Jäggi, A., Jakowski, N., Kern, M., Lee, T., Martin-Neira, M., Pierdicca, N., Semmling, M., Shum, C. K., & Zuffada, C. (2015). GNSS-Reflectometry with GEROS-ISS: Overview and recent results. In *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2015*

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# GNSS-Reflectometry with GEROS-ISS: Overview and recent results

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## ABSTRACT

GEROS-ISS (GEROS hereafter) stands for **GNSS RE**fectometry, **R**adio **O**ccultation and **S**catterometry onboard the International Space Station. It is a scientific experiment, proposed to the European Space Agency (ESA) in 2011 for installation aboard the ISS. The main focus of GEROS is the dedicated use of signals from the currently available Global Navigation Satellite Systems (GNSS) for remote sensing of the System Earth with focus to Climate Change characterisation. The GEROS mission idea and the current status are briefly reviewed.

## 1. BACKGROUND

The European Space Agency Directorate of Human Space Flight and Operations (HSO) released an announcement of opportunity in July 2011 in coordination with the Directorate of Earth Observation Programmes (EOP) soliciting scientific experiments for the International Space Station relevant to global climate change studies. 25 Letters of intent were received from 237 science team members. After a peer-review of the received proposals and a scientific and technical evaluation, the GEROS-ISS proposal [1] was accepted to proceed to Phase A feasibility studies.

## 2. MISSION IDEA

GEROS-ISS is a new and innovative ISS experiment primarily focused on exploiting reflected signals of opportunity from the GNSS satellites at L-band to measure key parameters of ocean surfaces which are relevant to characterise climate change. Secondary mission goals are global atmosphere and ionosphere observations using the GNSS radio occultation technique and the monitoring of land surface parameters utilizing reflected GNSS signals (see Fig. 1)

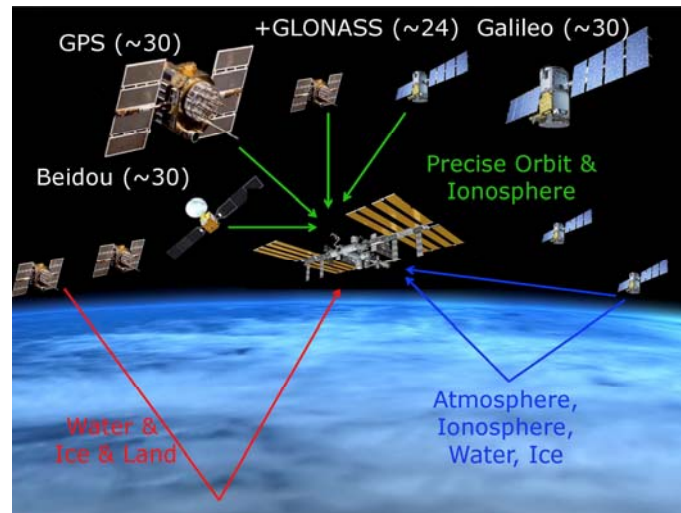


Figure 1. Schematic overview of the GEROS experiment to be installed aboard the International Space Station. Red lines indicate the reflectometry measurements for water, ice and land surface monitoring. Blue lines indicate GNSS RO and coherent reflectometry observations and the green lines symbolize the GNSS signals, received from zenith for Precise Orbit Determination (POD) of the GEROS payload and 3D upside ionosphere monitoring.

Complementing the Earth system observations from other current satellite missions, GEROS will especially pioneer the exploitation of GNSS remote sensing signals from the European Galileo system, thereby improving the accuracy as well as the spatio-temporal resolution of the derived geophysical properties compared to GPS only measurements. The additional use of signals from the Russian GLONASS, Chinese Beidou and Japanese QZSS navigation satellite systems is also intended.

GEROS will contribute to the long-term and climate relevant observation of the major components of the Earth System: Oceans/Hydrosphere, Cryosphere/Snow, Atmosphere/Ionosphere and solid Earth/Landcover with innovative and complementary aspects compared to established Earth Observation satellite missions. Therefore the data from GEROS will allow for climate change related scientific studies addressing the challenges of ESA's Earth Observation strategy [2].

GEROS will mainly provide mid- and low-latitude observations on submesoscale or longer oceanic variability (Fig. 2) with focus on coastal regions, surface ocean currents, surface winds, wave heights and the vertical atmospheric temperature, water vapour and electron density structure for a period of at least two years, probably longer, depending on the life-time of the International Space Station. The GEROS observations will lead to a better understanding of the climate system, e.g., of ocean barotropic variability, Rossby wave large-scale structures, eddy-current systems, fronts and coastal upwelling. GEROS hereby takes advantage of the capacious infrastructure aboard the ISS, which is a unique platform for the development of further and advanced GNSS reflectometry (GNSS-R) techniques, due to minor limitations with respect to, e.g., antenna size or availability of appropriate electric power. Due to the application of the novel and innovative GNSS-R remote sensing methods GEROS is also supported by the ESA Directorate of Technical and Quality Management (TEC).

GEROS will also provide a sensor calibration/validation option for other upcoming satellite missions including, e.g., the European twin platform ocean remote mission Sentinel-3 (planned launch mid-2015, duration 7-12 years), U.S./European SWOT (Surface Water Ocean Topography, launch foreseen 2020, duration three years) and the U.S./Taiwan 12 satellite constellation FormoSAT-7/COSMIC-II for GNSS radio occultation (planned launch 2017, duration at least 5 years). The GNSS remote sensing data from GEROS will also complement the innovative GNSS scatterometry measurements from the U.S. mission CYGNSS (CYclone Global Navigation Satellite System), which was 2012 confirmed to be funded from NASA's Earth System Science Pathfinder program and is currently foreseen for launch in 2016. CYGNSS (eight small satellites) will study the relationship between ocean surface properties, moist atmospheric thermodynamics, radiation and convective dynamics for the investigation of tropical cyclones [3].

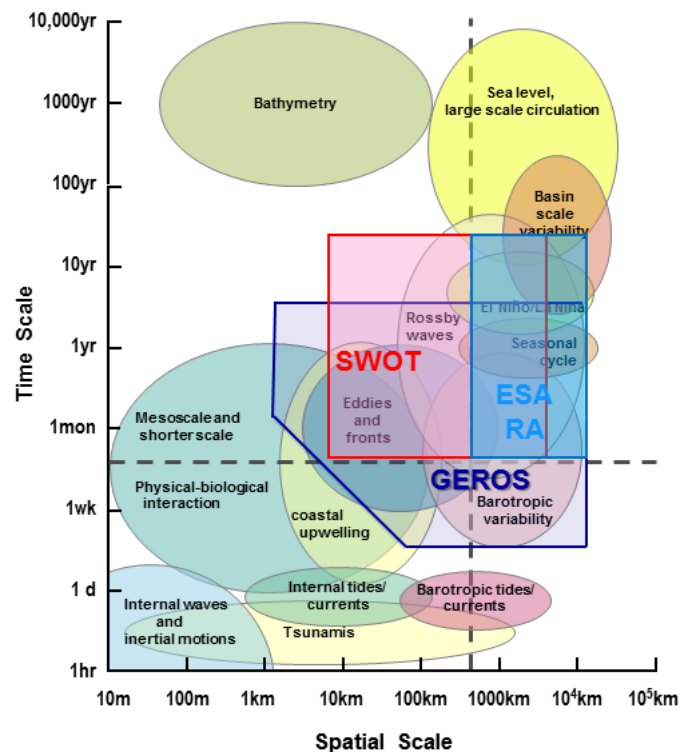


Figure 2. Oceanic observations carry signals of a wide range of related processes. The observed fingerprints of these processes have temporal time scales from 1 hour to thousands of years and spatial scales from ten to tens of thousands of kilometres. The figure illustrates the spatial and temporal scales for these processes and indicates phenomena, which can be investigated with Geros data complementary to and distinct from, the planned NASA SWOT mission and ESA's and NASA's radar altimetry missions (Revised from [4]).

### 3. MISSION GOALS

The primary mission objectives of Geros are:

- (1) to measure the altimetric sea surface height of the ocean using reflected GNSS signals to allow methodology demonstration, establishment of error budget and resolutions and comparison/synergy with results of satellite based nadir-pointing altimeters and
- (2) to retrieve scalar ocean surface mean square slope (MSS), which is related to sea roughness, wind speed and direction, with a GNSS spaceborne receiver to allow methodology testing, establishment of error budget and resolutions. As a secondary objective, 2D MSS (directional MSS) would be desirable.

Secondary mission objectives, which increase the scientific value of the Geros data, but are not driving the instrument developments, are:

- (1) to further explore the potential of GNSS radio occultation data (vertical profiles of atmospheric bending angle, refractivity, temperature, pressure, humidity and electron density), particularly in the Tropics, to detect changes in atmospheric temperature and climate relevant parameters (e.g., tropopause height) and to provide additional information for the analysis of the reflectometry data from Geros and
- (2) to assess the potential of GNSS scatterometry for land applications and in particular to develop products such as soil moisture, vegetation biomass, and mid-latitudes snow/ice properties to better understand anthropogenic climate change.

### 4. STATUS

GEROS was selected in result of a complex review process, initiated by ESA. The review results and decision on further activities was officially announced end of 2012. An interdisciplinary and international Science Advisory Group (SAG) of acknowledged experts in Oceanography, Geodesy, Atmosphere and GNSS Science started to work in June 2013 on details of the preparation of the Geros mission. This SAG consists of key members of the proposing Geros

team and additional experts, nominated by ESA. Two competitive industrial phase A studies for the Geros mission implementation will begin in the fourth quarter of 2014. In parallel the scientific study GARCA (GNSS-R Assessment of Requirements and Consolidation of Retrieval Algorithms) will be started, which is also funded by ESA. The main goal of GARCA is to support the assessment and consolidation of scientific requirements and the consolidation of retrieval algorithms for a spaceborne GNSS-R experiment, focusing on the Geros-ISS concept and its primary and secondary data products (sea surface height and ocean surface roughness). The main work hereby will be the development of an end2end-Simulator for the Geros-ISS measurements (Geros-SIM), and the evaluation of the expected geophysical data products. A Geros-SIM version will be executable through a web-server, freely accessible to registered scientists. In addition work packages are included, aimed to perform Observing-System Simulation Experiments (OSSE) to assess the oceanographic significance of the expected Geros-ISS measurements. Scientific experts will support the GARCA project and are involved in the planned work to test the developments and also to initiate the sustainable formation of an interdisciplinary Geros-ISS user community. According to the current schedule and in case of successful preparative studies and provision of appropriate funding, a launch of Geros can be expected for late 2019.

## 5. SCIENTIFIC STUDIES

Part of the preparation of the Geros mission and the work of the Science Advisory Group are dedicated scientific studies and campaigns. One example is an initial Observation System Simulation Experiment (OSSE), which is described in [5] to investigate the Geros capability for the observation of highly energetic mesoscale ocean currents (eddies) with changes of <20 cm sea surface within regions of <100 km. Knowledge on these eddies is important for the characterisation of nutrients and/or pollutants with many societal and scientific applications. Presently the tracking and forecasting of eddies is limited due to the capability of the current ocean altimetry missions. The OSSE used artificial Geros measurements (only GPS, conservative accuracy, 1 month) and a regional ocean model. Initial results indicate that Geros data, even with measurements from only one GNSS constellation and with conservative accuracy assumption, could be used to improve current regional ocean topography forecasting with special focus to highly energetic mesoscale currents. The OSSE investigations will be continued with data from additional GNSS satellites and from classical radar altimetry missions.

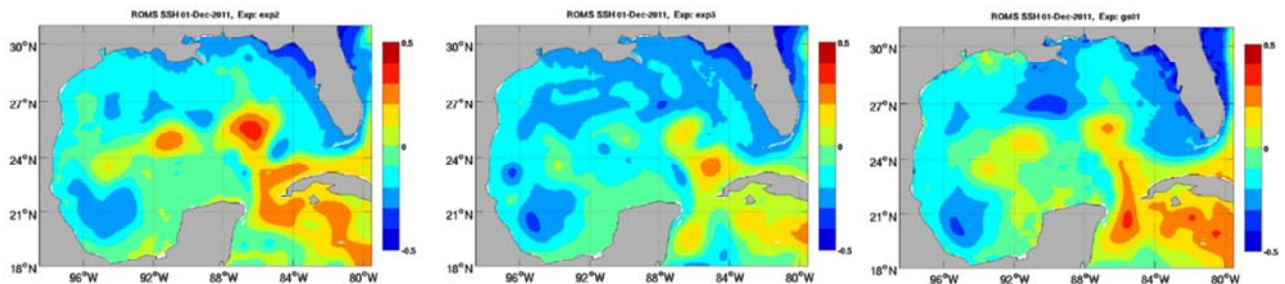


Figure 3. Sea surface topography of the Gulf of Mexico, reconstructed within an OSSE [5] after one month of artificial Geros GPS reflectometry measurements from the ISS (see text, control run: left; free: middle; assimilation: right). The colors indicate mesoscale variations of the sea surface height [m] related to energetic eddies. The investigation of these phenomena is a major Geros mission goal.

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